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A HIGH RESOLUTION DIFFERENTIAL PRESSURE GAGE FOR DEEP SEA USE.(U)
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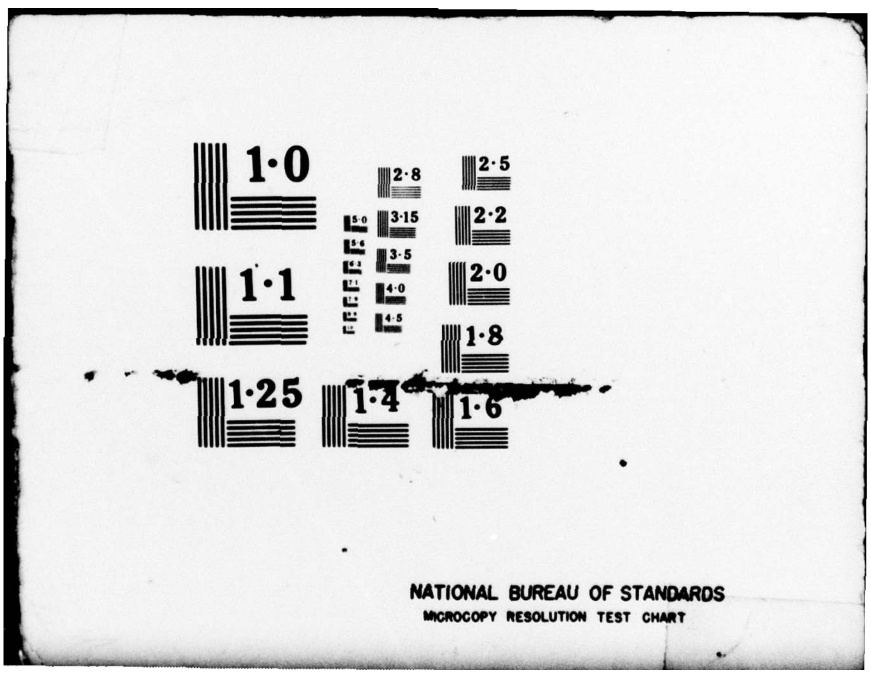
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MPL Technical Memorandum 145

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A HIGH RESOLUTION DIFFERENTIAL PRESSURE GAGE FOR DEEP SEA USE *

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ABSTRACT

The need for a differential pressure gage arose during the development of a deeply towed vehicle for use in the study of the micro-topography of the ocean floor. This "Deep Tow" is an instrument case designed to be towed from a surface ship at depths as great as 15,000 feet and with as much as 30,000 feet of towing cable. The ocean bottom is observed with a high resolution fathometer mounted on the case and it thus becomes necessary to monitor the vertical motion of the vehicle as the profile is being made.

ABSTRACT

The measurement of pressure is a convenient method for observing the vertical activity of a submerged instrument, however, in this instance it is desirable to have a vertical resolution of the order of 1/4 lb per square inch in ambient pressures of up to 7000 lbs per square inch. This precludes a direct measurement with an absolute gage as this resolution requirement presents very difficult problems to overcome, so an alternate approach was tried.

The concept is to capture a reference pressure at the operating depth, keep it isolated from the outside, and compare it to the sea pressure as the vehicle makes minor vertical deviations from its towed path.

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* This work represents results of research sponsored by the Office of Naval Research contract Nonr 2216 (05).

If the volume of the chamber in which the reference pressure is captured is V_o at temperature T and with no pressure differential relative to the outside, then its volume can be said to be:

$$V = V_o [1 - \alpha p + \beta (T - T_o)]$$

α and β represent the compressibility and coefficient of thermal expansion of the chamber and p is the differential pressure the gage will see.

If the chamber is closed at ambient pressure P_o and temperature T_o then, if the internal pressure is in general $P_o + p'$, the volume of liquid with compressibility α' and temperature coefficient β' will subsequently be:

$$V' = V [1 - \alpha' p' + \beta' (T - T_o)]$$

The actual external pressure will be P, thus $P' = P - P_o - p$. The liquid fills the chamber thus

$$V = V' \text{ and } p = \frac{P - P_o}{1 + \frac{\alpha}{\alpha'}} - \frac{\beta' - \beta}{\alpha + \alpha'} (T - T_o)$$

The pressure, p, measured by the gage is thus only approximately equal to the true pressure difference, $P - P_o$, and it is thus required that the design of the system make:

$$\frac{\alpha}{\alpha'} << 1 \text{ and } \frac{\beta' - \beta}{\alpha + \alpha'} \Delta T_{max} << P_{max}$$

The instrument consists of a reference chamber, in which a pressure can be isolated from the outside pressure, and a suitable differential gage element to measure the differences between the two. Several factors must be considered in the building of this chamber. First, the volume of the chamber is determined by the volume change of the sensing element, the compressibility of the fluid in the chamber, and an acceptable loss of sensitivity due to the volume change of the sensing element, which in this case is a Wiancko Mod. P2-1301 ± 10 psid unit. The volume change in this element is ± 0.9 cubic millimeter for full scale deflection. The fluid used is a hydraulic jack oil with a compressibility of 100 parts per million per atmosphere or a volume change of about 0.00068% with a pressure change of 1 psi. The volume of the gage changes by 0.0009 cc for a pressure change of 10 psi indicating that if this change of volume is applied to 1 cc of fluid the pressure will change by 140 psi. Therefore, if the reference

chamber volume is 140 cc the pressure will change only 1 psi when it accepts the 0.0009 cc volume change of the gage sensing element. This gives a 10% loss of sensitivity which is an acceptable compromise in the interest of keeping the gage small physically.

The structural requirements of the chamber are quite rigid. Although the chamber might never have to withstand a pressure of more than 10 lbs per square inch it has to be almost unyielding. As the compressibility characteristics of the fluid in the chamber are comparable to sea water, the chamber case must be many times less compressible than water so as not to transmit any appreciable part of the outside pressure change to the inside due to the case compliance. Any pressure change transmitted through the case or its seals would subtract from the true pressure changes thus causing errors in the gage readings. Any seals used must not have room to yield and valve seats must not be made of compliant material. The electrical feedthrough insulators must stand the full sea pressure. These are made of tapered brass pins 1-1/2 inches long with concentric tapered nylon sleeves installed with a press. They will withstand great pressure and have proven to be essentially unyielding, however, if this area were under-designed structurally, case distortion at great operating depths could introduce erratic operation or malfunction.

Due to the large difference in thermal expansion rates of metals and fluids this instrument is quite sensitive to temperature changes. It is possible to predict the error in pressure reading due to temperature variations by comparing the change in volume of the fluid and metal used and calculate the pressure change due to this change in volume. To minimize temperature effects aluminum alloy is used due to its high thermal expansion and heat conducting properties. It is also possible to make a completely temperature compensating chamber by constructing a bimetal compartment. Space restrictions in this instrument indicated that a separate unit be used to compensate for temperature changes.

The temperature compensator is made of two concentric sections of tubing sealed together at one end and capped at the other forming a small chamber for fluid. The inside section is made of stainless steel and the outside section is aluminum alloy. Due to the different expansion rates of these metals the volume of the chamber changes more than the volume of the oil. This is connected by a small tube to the main unit of the gage giving the system a neutral steady-state temperature characteristic. The

only temperature effect occurs as the temperature of the system is equalizing. As this small chamber is actually a part of the reference chamber it has the same structural requirements. The volume of the temperature compensator is determined by the differential expansion rates of the material of the reference chamber and the fluid in it compared to the differential expansion rates of the two metals used in the compensator. In this instance the oil-aluminum ratio is approximately six times the steel-aluminum ratio, therefore the effective volume of the compensator must be six times the total volume of fluid in the system.

The electronic circuitry involved with the system is not complicated. The Wiancko gage produces a 0-5 v dc signal which is linear to differential pressure. This voltage acts as a frequency control of the dc controlled oscillator which is one of the telemetering channels of the "Deep Tow" instrument. A solenoid-operated by-pass valve parallels the differential pressure sensing instrument to equalize the reference chamber pressure when measurements are not being taken. This valve is held shut electrically during periods of observation, but a frequency sensitive safety device will release the valve if there is an over-pressure. It is also fail-safe as it automatically opens in case of a power interruption.

The towing cable is equipped with a small coaxial cable in its core which carries the instrument power, telemetering signals, and the control signals for the device. This permits control of the solenoid valve from the ship's lab. The pressure signal is demodulated and recorded as a depth variation or can be applied electrically to the fathogram as a depth correction.

This device is far from perfect and many refinements could easily be incorporated if another instrument were to be constructed but it appears to be adequate for the job at hand. Probably the most useful improvement would be to speed up the temperature correction time.

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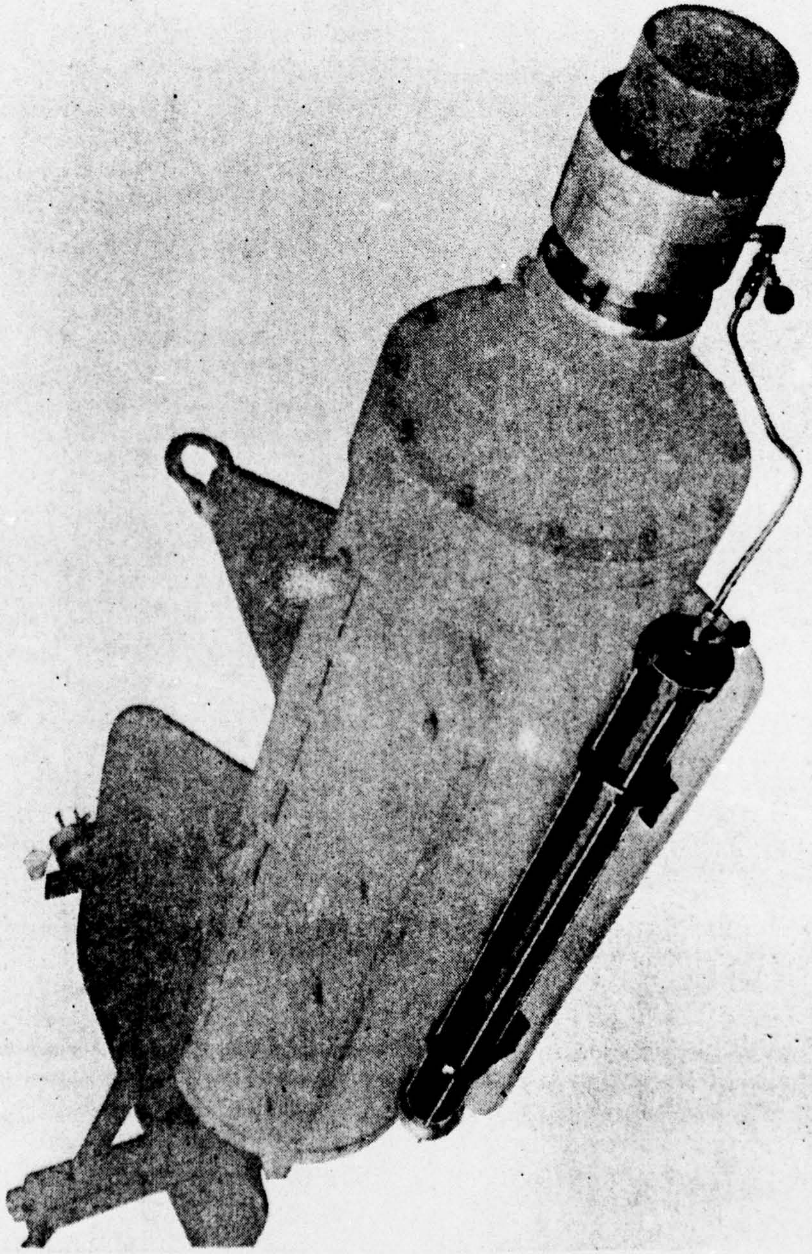
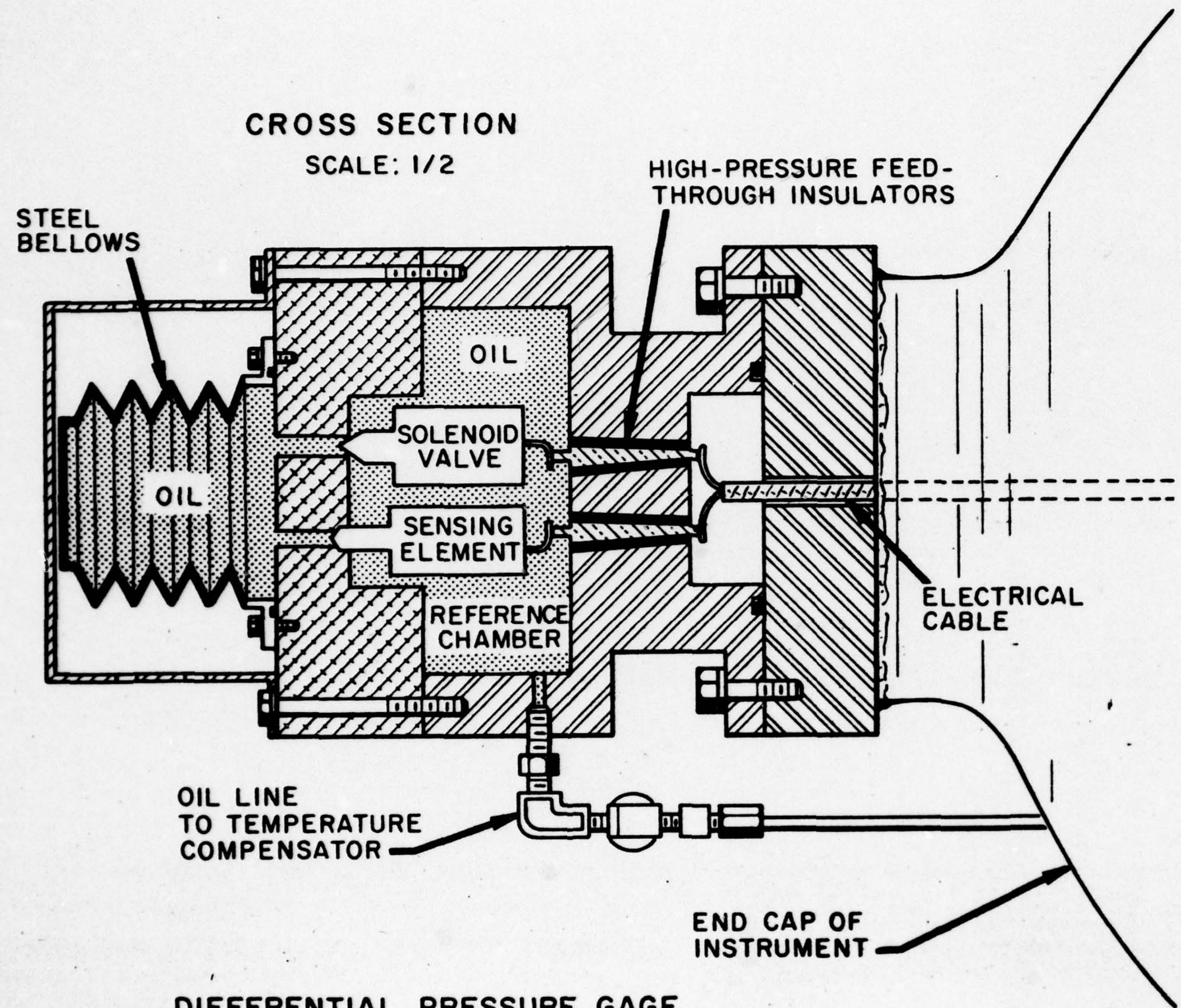


Operational Performance

The development of this instrument was slowed somewhat because testing could be done only in deep water, but after the usual amount of "de-bugging" it was tested to depths as great as 11,000 feet with no noticeable loss of sensitivity. It was then put into service as a device to apply depth corrections to a fathogram in the following manner.

The "Deep Tow" echo sounder is a short pulse, narrow beam device whose output is fed into a high-speed recorder which can resolve depth changes of the order of 1/2 foot. As the tow cable transmits a fair amount of the ship's vertical motion to the "Deep Tow" vehicle this appears on the bottom profile recording as changes in depth. The period of this vertical motion is quite long compared to the transit time of the acoustic pulse in the water which makes it possible to use the output of the gage to correct the depth record for these errors.

The depth recorder key contacts initiate a pulse to which is imposed both a fixed time delay and the variable time delay which is derived from the gage output. The output of the gage is transmitted up the tow cable on a frequency modulated carrier. This is demodulated and becomes a slowly changing dc voltage which represents the position of the vehicle above or below the previously selected reference depth. If the vehicle is above the reference depth, for instance, the pressure gage signal is used to send the transmitted pulse sooner to compensate for the increased travel time necessary. This makes the echo appear on the record in the same place that it would have been if the vehicle were still at the reference depth, effectively removing the errors due to wave action. It also causes the recording of the transmitted pulse to appear as the actual wave motion giving a convenient method for checking the operation of the system.



DIFFERENTIAL PRESSURE GAGE

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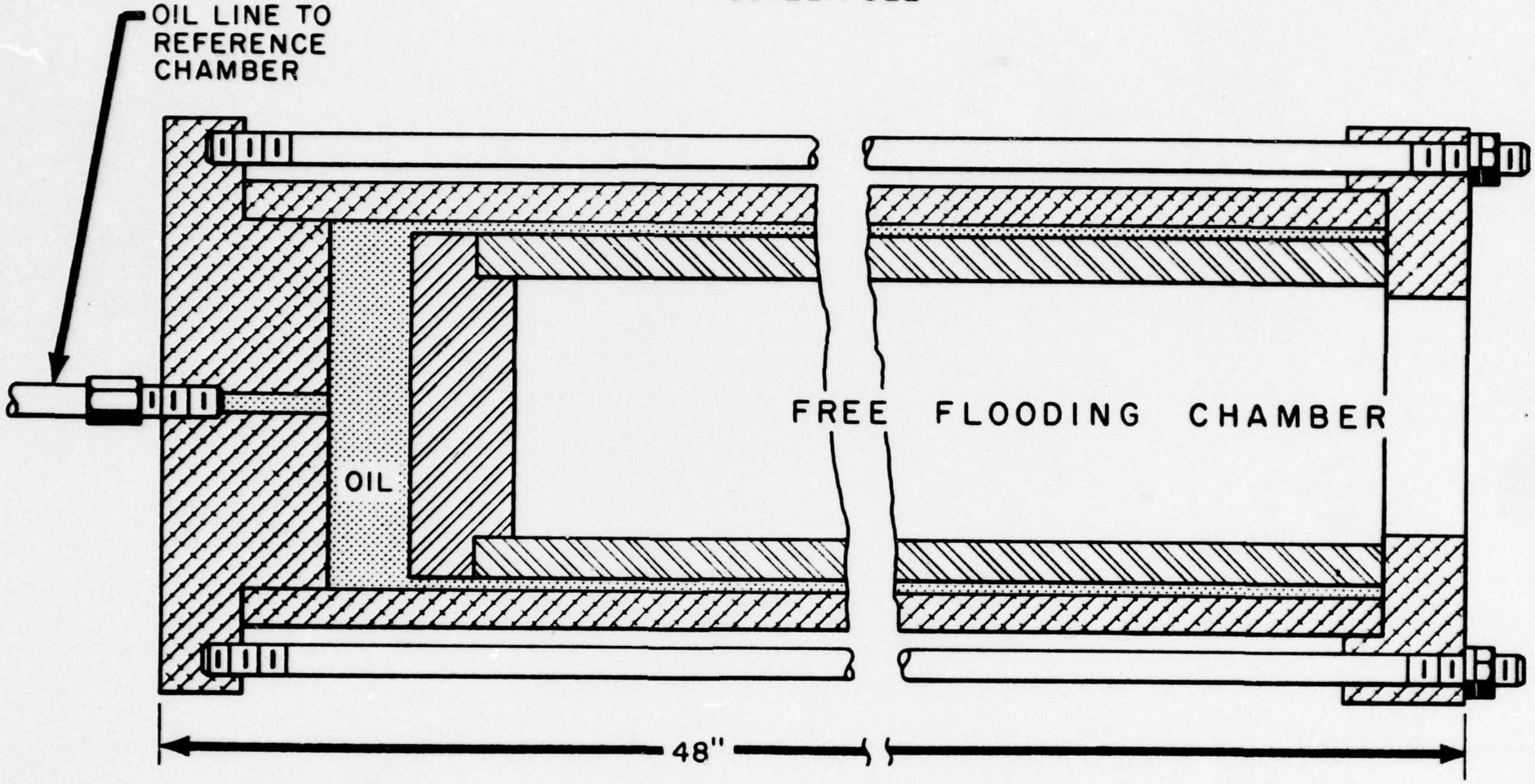

TEMPERATURE COMPENSATOR

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